CHAPTER 10

Application of Mycorrhizal Symbiosis in Forestry Practice

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I. Introduction

A. Early Findings on the Importance of Mycorrhizal Infection

The necessity of mycorrhizal association for forest trees was first noticed when experimental plantations of exotic pines in different parts of the world invariably failed, until suitable mycorrhizal fungi had been imported in one way or another (e.g., Kessell, 1927; Roeloffs, 1930; anonymous, 1931; Oliveros, 1932; Clements, 1941; Briscoe, 1959; van

Suchtelen, 1962; Gibson, 1963; Madu, 1967).[1] The Russian scientist Vysotskii, as early as 1902, suggested using mycorrhizal inoculation in afforesting grasslands. Likewise, in America the importance of introducing mycorrhizal fungi was detected when afforestation was started in formerly treeless areas (McComb, 1938; White, 1941).

On the other hand, in some countries cultivation of exotic pines was started successfully without intentionally importing mycorrhizal fungi. Thus, there are no historical data on importation of mycorrhizal fungi to South Africa or New Zealand, both of which today are famous for their extensive exotic pine plantations. Most likely, however, mycorrhizal fungi have been imported unintentionally into these countries too, and in present plantations infection is well established. Long ago the first pines were introduced into many countries as potted plants with mycorrhizal roots. When such seedlings were planted in natural soil where mycorrhizal fungi were lacking, the fungi usually spread along with the roots (White, 1941; Mikola, 1953). In general, grassland soils contain no harmful factors inhibiting mycorrhizal fungi. Many fungi also spread easily through air in the form of spores or in other ways to such a degree that special measures are often necessary, in scientific experiments, to protect nonmycorrhizal seedlings in sterilized soil from outside infection.

B. Problems in Natural and Man-Made Forests

The practical application of mycorrhizal symbiosis to forestry is primarily in introduction of exotic tree species and establishment of man-made forests. When exotic tree species with mycorrhizae are cultivated in new areas, several questions should be answered. What species of mycorrhizal fungi should be introduced with the trees, or is it at all possible to choose the symbionts for the trees? Furthermore, in which form should the fungi be imported and how should inoculation be performed? How can importation and inoculation be made in such a way that the introduction of pathogens is avoided?

The same kinds of problems may occur on a smaller scale in areas where some mycorrhizal fungi already exist. Forest nurseries are often established on former agricultural soils or on other sites which have long been treeless. Although in such cases experience shows that mycorrhizal infection usually takes place without artificial inoculation, it may be possible to direct favorable mycorrhizal development by introducing

[1] The early reports have been reviewed by Hatch (1936) and Rayner (1938), for instance, and the later ones by Mikola (1970).

new fungal species or by improving soil conditions for the fungi already present.

In natural forests there are few possibilities of applying our present knowledge on ectomycorrhizal symbiosis. Mycorrhizal fungi are present everywhere, and most probably, as the result of competition and long evolution, undisturbed soil already contains those species that are best adapted to prevailing ecological conditions. Under such circumstances introducing new fungal species into the soil has little chance of success. Thus, "99 per cent of all practising foresters will not have to lose any sleep over the problem of mycorrhizal infection" (Wilde, 1944).

In the management of natural forests, however, artificial regeneration through seeding or planting is gaining more and more importance. Mycorrhizal relations also deserve more consideration, particularly when tree seedlings are transplanted from the nursery to natural forest soils.

II. Mycorrhizae in Forest Nurseries

A. Inoculation of Nursery Soil

1. Importance of Inoculation

Early reports on the failure of exotic pines usually came from forest nurseries. Afforestation trials were started by establishing nurseries where seedlings suffered and died, but after introduction of appropriate fungi, healthy and vigorous seedlings with mycorrhizae were produced. Such experiences were reported in areas where native ectotrophic tree species were lacking, particularly in many tropical and subtropical countries. Most of the common tree species of cool and temperate forests belong to the ectotrophs and inoculation is usually not needed there. However, nursery guides for the tropics (e.g., Parry, 1956; Letourneux, 1957) normally give instructions for soil inoculation. The same techniques have also been recommended for establishment of new nurseries in the temperate zone in treeless regions, such as the American prairies (Stoeckeler and Slabauch, 1965) or areas which have long been in agricultural use (Wakeley, 1954; Stoeckeler and Jones, 1957). In the Soviet Union the need for soil inoculation was first observed when nurseries were established for raising tree seedlings for shelterbelt plantations in the steppes. Numerous studies have since been conducted there to find out when the inoculation is needed and when it is unnecessary (see references in Imshenetskii, 1967; Lobanow, 1960; Shemakhanova, 1967). Usually, however, oak shelterbelts in the Soviet Union have been established by direct seeding (cf. Section III,A).

Mycorrhizal infection can easily spread by spores carried by air currents or in other ways. Thus, new nurseries may become infected even without intentional inoculation. The inoculation of the first pine nurseries has proven most necessary on remote tropical islands, such as Trinidad (Lamb, 1956) or Puerto Rico (Briscoe, 1959), where chances of an airborne or other incidental infection are smallest. On continents, however, inoculation of the first pine nurseries has also proven necessary, in general, if these have been established at a great distance from older nurseries or plantations, as is clearly shown by examples from Nigeria and Zambia (see Mikola, 1970).

When it was discovered that exotic pines showed a need to form mycorrhizal associations, an annual inoculation of nursery soil was adopted as a standard routine in several countries and detailed instructions for nursery technique were issued (e.g., May, 1953; Waterer, 1957). If the nursery soil is once inoculated, however, an adequate mycorrhizal population is established and repeated inoculation has no further effect.

If a nursery is extended or a new one established in the vicinity, inoculation of the new section is not quite necessary, for the infection usually comes from the old section through the air, attached to tools, in the roots of transplants, or in other ways. A year or two may elapse, however, before enough fungi have spread from these infection points to cover the whole nursery. Therefore it is advisable to inoculate even new sections of old nurseries, in order to secure a healthy and even growth of the seedlings from the very beginning. This also holds true for new nurseries in the vicinity of old ones or established plantation.

In soils which have long been in agricultural use, mycorrhizal fungi usually are not completely lacking but the population density may be low or the existing fungi may belong to less effective species. If a nursery is established on such soil, introduction of new fungal species may be beneficial. Inoculation alone is not often an effective measure of improving the growth of seedlings and development of mycorrhizae, but, in addition, soil properties, such as acidity, fertility, or organic matter content, must be corrected in order to favor the introduced fungi (Dominik, 1961). In general, correction of soil conditions is a more successful procedure in forest nurseries on agricultural soils than effort to introduce new fungi (Sobotka, 1963).

In order to control weeds and pathogens, partial soil disinfection with steam or chemicals is a common practice in modern nursery management. Then a new question arises: What happens to mycorrhizal fungi with such drastic soil treatment? There is a possibility that they are killed at the same time, and if so, the appropriate fungal population should be returned to the soil by artificial inoculation. Partial soil disinfection usually does not destroy the mycorrhizal population completely,

but it can retard commencement of root infection (Hacskaylo and Palmer, 1957; Laiho and Mikola, 1964). Partial sterilization probably destroys the fungi in the uppermost soil layer, but deeper in the soil they survive and infect the roots when the roots reach that layer, or they may grow upward back to the surface layer. Furthermore, airborne reinfection is always possible in forested areas. A considerable delay in commencement of mycorrhizal infection can be harmful and therefore some kind of soil inoculation after partial sterilization may be advisable (cf. Section III,B,1). Pine needles or forest litter serve as an effective inoculum when used for mulching the nursery beds. Some chemical pesticides, however, may cause severe growth disturbances in seedlings and effectively exterminate mycorrhizal fungi; then both inoculation and correction of soil conditions are necessary (Iyer *et al.*, 1971).

Sometimes partial soil disinfection has even encouraged mycorrhizal development in nurseries. This has happened when formaldehyde and allyl alcohol have been used as soil disinfectants. A probable explanation may be that *Trichoderma viride*, a common soil saprophyte, is rather resistant to these chemicals and therefore dominates in the soil after their application. This fungus, in turn, somehow favors the growth of some mycorrhizal fungi (Laiho and Mikola, 1964).

According to present Finnish nursery technique, seedlings are raised on peat substrate in plastic greenhouses. Inoculation is not needed even though the peat, which had been dug from treeless bogs, originally contained no mycorrhizal fungi. Richly mycorrhizal seedlings grow on such a peat substrate, probably because of airborne infection.

2. *Techniques of Inoculation*

Three types of inocula have been used for mycorrhizal inoculation in nurseries: (a) soil from natural forests, plantations, or old nurseries; (b) mycorrhizal seedlings; and (c) pure cultures of mycorrhizal fungi. Of these inocula, soil has been most widely used in forestry practice. For the first introduction of mycorrhizal fungi, a thin layer of soil taken from an old nursery or an established plantation was usually spread on the top of a nursery bed and mixed thoroughly with the soil beneath. The same method is still commonly used in various parts of the world if plants are raised in open beds on natural soil.

In many nurseries, however, in the tropics and subtropics in particular, it is customary to raise seedlings in various kinds of containers, such as clay pots, wooden boxes, or plastic tubes, or in specially prepared beds ("Swaziland beds"), and soil for them is prepared by mixing various ingredients (Mikola, 1969a). The composition of the soil mixture varies in different nurseries. In East Africa, for example, the "Muguga" mixture (May, 1953) was once widely used. If pines were grown it was

customary to add a certain amount, usually 10–20% of volume, of pine soil, i.e., top soil from a pine plantation. A sufficient amount is 10% of the volume, and, if procurement of pine soil is difficult, there is no reason for using larger amounts. Since old nursery soil, which already contains sufficient amounts of mycorrhizal fungi, is generally applied to the new mixture, introduction of new pine soil is no longer necessary and has been discontinued in old nurseries. Different soil mixtures and the use of pine soil for them have been reviewed by Mikola (1970).

Instead of incorporating pine soil into the mixture for transplant beds or containers, seedlings can be inoculated individually by placing about 1 teaspoonful of pine soil at the base of each seedling. This method is cumbersome and time-consuming, but it may be recommended if there is a need for economizing pine soil and inoculation can be timed properly (in tropical nurseries about 1 month after transplanting).

The use of living plants as mycorrhizal inoculum in large-scale nursery practice is uncommon. This method was first applied in Indonesia (Roeloffs, 1930) and is still used there (Becking, 1950; van Alphen de Veer *et al.*, 1954). Vigorous mycorrhizal pine seedlings are planted in seedbeds at 1- to 2-m intervals, and from these mother trees the infection spreads to adjacent seedlings, as can be seen from the green color and improved growth of seedlings. At the time of lifting, some seedlings can be left in beds as mother trees to infect the next crop.

The Indonesian technique of inoculation has also been used on an experimental scale in some other tropical countries. In Indonesia it is said to be the most reliable method for inoculation of *Pinus merkusii*, whereas the use of soil inoculum has resulted in failures (van Alphen de Veer *et al.*, 1954).

The use of pure cultures of mycorrhizal fungi has been repeatedly recommended as the soundest method of inoculation from the scientific point of view and has been commonly used in many experiments. However, because of several difficulties, pure cultures have been used in large-scale nursery practice only in some exceptional cases. First of all, it is not yet known which fungal species should be used under different conditions. Although pure-culture experiments have revealed great physiological differences between various fungi, very little is known so far about the symbiotic efficiency of individual species (cf. Section II,C). Another difficult problem is production of sufficient amounts of mycelia of suitable fungi for mass inoculation of nursery beds.

Ectomycorrhizal fungi, in general, are hard to cultivate. Many probable mycorrhiza-formers have never been isolated into pure culture, and those species which have been isolated, often grow slowly, require specific growth substances and are sensitive to various growth-inhibiting

substances (Melin, 1946). For these reasons efforts of pure-culture inoculation have often failed. For pure-culture inoculation to be successful, the introduced fungus must be able to compete with the natural microbial population of the soil, and to achieve this, large amounts of inoculum must be applied and conditions in the soil made favorable for the introduced fungus.

Pure-culture inoculation has reached the stage of practical application in Austria (Moser, 1958b, 1959a, 1962). Prerequisities for successful application of this method are created by the fact that *Boletus plorans* probably is a very suitable symbiont for *Pinus cembra* at high elevations near the timberline, and this fungus is easy to cultivate and grows reasonably well in pure culture. Because this species is most often lacking in the nursery soils of valleys, it is introduced artificially, so that the seedlings may have an efficient symbiont in their roots at the time of transplanting into the field. Since afforestation is conducted on alpine areas above the present timberline, *Boletus plorans* perhaps does not exist in the soil of these planting sites either; thus, it is introduced with the inoculated seedlings.

For mass production of pure-culture inocula, the fungus is first grown in a nutrient solution in Erlenmeyer flasks (Moser, 1958b). The mycelia are transferred from the flasks to the same solution in 10-liter tanks which are aerated intermittently. After a few months of growth in the tanks, the mycelia are transferred to a mixture of vermiculite and peat moistened with the same nutrient solution. If sufficient moisture and good aeration are maintained the mycelia grow throughout the substrate in a few months and the inoculum is ready for use.

Rather similar methods of mass production of fungal cultures for nursery inoculation have been described by Voznyakovskaya and Ryžkova (1958, cited by Shemakhanova, 1967), Sobotka (1955), Shemakhanova (1967), Takacs (1967), and Park (1971). In all these techniques, mycelia are first grown in liquid culture and then mixed into a suitable solid substrate (peat, sawdust, needle litter, wheat grain, or straw), and after several months of incubation the mixture is used for nursery bed inoculation. Because the suitability of different fungi for different tree species and soil conditions is not known, pure cultures of several fungal species are sometimes mixed to make the final inoculum.

According to the Austrian technique, the inoculum is sent from the laboratory to the nursery in plastic bags and used immediately. The dosage is 3–4 liters of inoculum per m^2 of nursery bed. The inoculum is worked lightly into the surface soil and young *Pinus cembra* seedlings are immediately transplanted to the inoculated bed (Moser, 1959a).

Pure-culture inoculum can also be mixed into sterilized soil, and either

immediately or after a few weeks of incubation this soil can be applied to nursery beds or used for filling boxes or plastic tubes. Individual inoculation of seedlings grown in pots or plastic tubes has also been practiced on an experimental scale. Results of these methods are so far uncertain.

Besides pure cultures, spores or crushed sporophores of mycorrhizal fungi have been used for inoculating nurseries. Fresh sporophores have been crushed and then mixed into nursery soil in the same way as mycorrhizal soil and pure-culture inocula are used. To increase the infective capacity, crushed sporophores of mycorrhizal fungi have been sometimes added into soil inoculum. Dried sporophores also have been used in some cases when transportation of inoculum for a longer distance has been necessary.

Spores have been used in attempts to inoculate seeds. Although mycorrhizal infection is known to spread easily through the air (Robertson, 1954), efforts using spores for artificial inoculation have not always been successful. Some positive results have been reported (e.g., Klyushnik, 1952; Theodorou, 1971), but the method has not yet reached the stage of practical application.

3. *Shipment and Storage of Mycorrhizal Inocula*

Mycorrhizal infection is usually transmitted from one country or nursery to another in the form of soil inoculum. Because plant protection regulations in many countries prohibit importation of unsterilized soil, great difficulty has been sometimes experienced in procuring mycorrhizal inocula. In fact, in several countries the mycorrhizal infection has been smuggled illegally, or legal procedures have caused considerable delay. Examples of such cases have been described by Mikola (1970).

To keep mycorrhizal fungi alive and in active condition, the time of transportation should be made as short as possible and the soil must be kept moist. According to Letourneux (1957), "nine times out of ten failure occurs if the shipment takes more than eight days." At the present time international air transport is feasible if plant quarantine procedure does not cause undue delay.

There are other reports, however, indicating that mycorrhizal soil can be stored in moist condition for considerably longer times. According to Olatoye (1966) soil which had been stored in plastic bags for 15 months was as effective as freshly collected soil. In the Soviet Union soil for inoculation purposes has been collected in autumn, stored in a moist condition over the winter and applied in the spring with good success (Lobanow, 1960). Some mycorrhizal fungi may survive a long time even in dry soil, probably in the form of spores or sclerotia.

Shemakhanova (1967) has shown that soil which had been stored for 15 months in a dry condition, was as effective as fresh soil. It is possible, however, that in dry soil some fungal species survive, whereas some others, perhaps the most beneficial symbionts, die out. The black mycorrhizal fungus *Cenococcum graniforme* is known to be very drought-resistant (Worley and Hacskaylo, 1959; Trappe, 1962b). Thus, storage of soil in a dry condition may exert a selective influence on the fungal population, and, therefore, it is recommended to keep mycorrhizal soil moist during shipping and storage.

It is also desirable to protect soil inoculum from excessive temperatures, because mycorrhizal fungi, in general, are not very heat-tolerant. In tropical nurseries mycorrhizal soil is usually stored under shelter to protect it against heat and desiccation.

Although the first introduction of ectomycorrhizal fungi into many countries took place in roots of potted plants, living seedlings have seldom been used intentionally for shipping inoculum. New nurseries have often been started with transplants from older nurseries and then, of course, mycorrhizal fungi were carried at the same time. In a few cases it is known, however, that living seedlings have been shipped intentionally from one country to another for mycorrhizal inoculation, because plant quarantine regulations prohibited importing soil inoculum.

Living seedlings provide a good means of preserving mycorrhizal infection. Mother trees which are left in seed beds after lifting the other seedlings transfer the infection to the next crop. This method is particularly practicable under climatic conditions in which a prolonged interval is customary, during the dry season, between lifting seedlings and sowing of the next crop.

Pure cultures of mycorrhizal fungi are shipped and stored in the same way as all the other microbial cultures. Since practical application of pure cultures for mycorrhizal inoculation has, so far, been rare, shipping and exchange of pure cultures of mycorrhizal fungi have taken place for research and experiments only.

Spores of mycorrhizal fungi have been shipped sometimes in the form of dried and crushed sporocarps. Since very little is known so far about the possibilities of using spores for inoculation, information about their storage and survival is also scanty. According to Russian experience, spores of some mycorrhizal fungi can maintain viability for 1 year if they are kept in dry conditions (Lobanow, 1960).

4. *Advantages and Drawbacks of Different Methods of Inoculation*

Application of mycorrhizal soil is the easiest and simplest method of nursery inoculation. It is also quite a reliable method. Nevertheless, it has several drawbacks.

The bulkiness of soil inoculum can be a serious obstacle in practical work. For nursery inoculation a rather large amount of soil is needed. According to African experience, pine soil must constitute at least 10% of the volume of soil mixture for seedling tubes or Swaziland beds. Procuring pine soil is no problem if there are pine plantations in the neighborhood of the nursery, but if a planting program is started in a new, remote area transportation of sufficient amounts of pine soil for the first nurseries may involve difficulties and high costs.

Soil inoculum contains an indiscriminate mixture of both mycorrhizal fungi and other soil organisms, and perhaps root pathogens and parasites. It is because of the risk of introducing pests that the import of unsterilized soil is prohibited in many countries. Illegal smuggling cannot be accepted. In the few known cases of illegal smuggling, the inoculum has first been mixed with a small amount of soil, in which pine seedlings have been planted. After this soil has been infected throughout, it has been used to inoculate a still greater amount of soil, and the process repeated until a sufficient amount of soil has been available for inoculating nursery beds.

Thus far there are no uniform regulations concerning international exchange of mycorrhizal inocula and necessary precautions. An appropriate system would be desirable to make safe legal import of inocula possible. Fortunately, in no known case has a pest been introduced with mycorrhizal soil inoculum, but the risk still exists.

Soils from natural pine forests and healthy plantations most probably contain a large variety of mycorrhizal fungi, among them species which are effective and well suited for nursery conditions. On the other hand, soil inoculum from an old nursery may contain damping-off fungi, nematodes, weed seeds, and other nursery pests. It is probable that infections were often introduced this way. Soils cannot be disinfected without killing mycorrhizal fungi. Therefore, soil for inoculation should not be taken from old nurseries, and even natural forests or plantations, where *Armillaria mellea, Phytophthora cinnamomi,* or other dangerous pathogens are known to occur, should be avoided.

The application of living seedlings or mother trees for inoculation is quite a reliable method. The species of fungi are usually not known, but if the mother trees are vigorous and healthy and if inspection reveals good mycorrhizal structure in their root systems, the conclusion can be made that efficient fungi are present. If the spread of infection from the mother trees is slow, only 40–50 cm/year, some unfavorable soil properties, such as excessively high pH, are indicated. This can be corrected by appropriate soil treatment, e.g., acidification. Infection usually spreads faster in sterilized soil; therefore soil sterilization is recommended before planting mother trees.

Nursery inoculation with mycorrhizal soil, if successful, usually results in faster and more even infection than is accomplished with mother trees. Inoculation with mother trees, however, has been successful even in cases where application of mycorrhizal soil has failed (van Alphen de Veer *et al.*, 1954).

When a new nursery is established, the first crop often consists of seedlings transplanted from an older nursery. This is an easy method of infecting the new nursery. Likewise, the first field plantations in some areas have been established with imported seedlings. With regard to shipping living plants for long distances, the same objections as to shipping soil are applicable. Seedlings are perhaps not quite as heavy and bulky as soil but they need more care, e.g., irrigation, during the transportation. Pests and diseases, especially needle diseases, can be carried with seedlings as well as with soil inoculum. Importation of living plants is often more strictly controlled than that of unsterilized soil, and illegal smuggling is more difficult. For the above reasons, living plants have seldom been used particularly for transmission of mycorrhizal infection. To reduce the risk of carrying pests, various possibilities are available. For example, seedlings can be washed or treated with insecticides and transplanted into sterilized soil before shipping; the shoots can even be treated with fungicides.

Theoretically, pure cultures and spores would be the best inocula; therefore their use is often recommended (Bakshi, 1967). Pure cultures need little space and are easy to handle, and there is no risk of introducing pests. So far, however, because of technical difficulties and unknown factors involved, pure-culture inoculation has been used very little in nursery practice on a field scale.

One drawback is the slow growth of mycorrhizal fungi in pure culture. Production of sufficient amounts of mycelia for field inoculation is cumbersome and time-consuming. It is not possible under ordinary nursery conditions, and for this reason the inoculum must be produced in a laboratory and shipped to nurseries for use. The whole procedure is rather expensive.

Furthermore, experience has shown that pure-culture inoculation is an unreliable method. The fungus often dies immediately after inoculation; probably because of competition with other soil fungi, mycorrhizal infection does not take place. The chances of success can be improved by soil sterilization before inoculation and by using a rather large amount of inoculum. If large amounts of pure-culture inoculum are needed new problems of procurement and handling may appear. The rate of application of 3 liters of pure culture inoculum per m^2, for instance, as is customary in the Austrian nurseries, corresponds to 30 m^3/hectare.

The greatest obstacle for the use of pure cultures is, however, the lack

of information about which fungal species should be used. According to the present state of knowledge concerning the efficiency of different species, use of a mixture of pure cultures of several species may be recommended (Takacs, 1967). It is not known, however, whether the species that gain dominance in the mixture are also the best mycorrhizal symbionts. Furthermore, there is a great number of potential mycorrhiza-formers which have never been isolated into pure culture (cf. Modess, 1941; Trappe, 1962a).

The same factors which restrict the use of pure cultures for inoculation on a nursery scale, also apply to the use of spores. Spores would have many advantages. They need little space, they are easy to send from one country to another, and the risk of disease transmission is eliminated. There is the slight disadvantage, however, that spores can only be collected during a brief period of the year, which may be a less favorable season for inoculation, and therefore spores might have to be stored for a rather long time.

If a sufficient knowledge about spore viability and symbiotic efficiency of different fungal species can be obtained and reliable methods of inoculation developed, then spore inoculation may become a standard technique. It must be kept in mind, however, that there may also be effective mycorrhizal fungi which form no sporophores or whose spores for some reasons are difficult to obtain.

B. Promotion of Mycorrhizal Development

In the natural range of ectotrophic tree species hardly any soils are completely devoid of mycorrhizal fungi. The poor development of mycorrhizae, and at the same time seedlings, in nurseries is probably most often not due to the absence of appropriate fungi but to adverse soil conditions which affect the seedlings either directly or indirectly through mycorrhizal fungi. Since close correlation exists between the good growth and healthy condition of seedlings and the abundance and morphology of mycorrhizae (e.g., Göbl, 1967), the suitability of nursery soils can be evaluated by examining mycorrhizal relations, and soil management in nurseries should aim at improving conditions for mycorrhizal fungi. Although an improvement in the quality of nursery stock is the ultimate goal of soil amendment, this aim is partly achieved through activity of mycorrhizal fungi. Mycorrhizae are sensitive to alterations in soil conditions and, consequently, the effect of soil amendment is perhaps first detectable in mycorrhizal relations.

Adjustment of soil conditions is often an indispensable prerequisite

for successful mycorrhizal inoculation (Göbl and Platzer, 1967). Fertilization, acidification, and addition of organic matter are the most common measures used for promoting mycorrhizal development in forest nurseries.

McComb and Griffith (1946) have shown that mycorrhizal development in a prairie soil nursery could be promoted with phosphorus fertilization. White pine (*Pinus strobus*) seedlings which without inoculation and fertilization were chlorotic and nonmycorrhizal, started vigorous growth and developed numerous mycorrhizae as a result of a moderate phosphorus fertilization. Thus, the soil contained some mycorrhiza-forming fungi but they were in an inactive condition and were activated by phosphorus. Still better growth and mycorrhizal development, however, was achieved with inoculation, i.e., by introducing new fungal species which established a symbiotic relationship with the pine without additional phosphorus. Douglas fir (*Pseudotsuga menziesii*), however, behaved differently in the same experiment. Phosphorus fertilization improved the growth of seedlings, but no mycorrhizae developed without inoculation. The conclusion can be made that some fungal species originally present in the soil were able, when activated with phosphorus, to form mycorrhizae with white pine but not with Douglas fir, or perhaps pine roots were activated somehow by phosphorus to establish symbiosis more readily with local fungi.

The development of mycorrhizae in nurseries can also be promoted by the addition of other nutrients. When there is a severe shortage of some nutrients, usually N, P, or K, the number of mycorrhizae is small and their structure abnormal, but with moderate and balanced supply of the major nutrient, optimum development is achieved (Hatch, 1937; Björkman, 1942, 1949, 1956). Excessive fertilization, with nitrogen in particular, also reduces the intensity of mycorrhiza formation, which may be harmful for the survival of the seedlings after planting in the field (cf. Section III,B,1 and Chapter 9).

Most ectomycorrhizal fungi are acidophilic, their pH optimum usually ranging from 4.0 to 6.0 (Modess, 1941). Since forest nurseries often have been established on former agricultural soils which have been previously limed, acidification may be an essential measure to improve soil conditions for mycorrhizal fungi. Acidification alone may be effective or it can be used in conjunction with inoculation. Tserling (1960), for instance, showed that soil inoculation alone was not sufficient to establish mycorrhizal association on larch in an alkaline chernozem soil and that acidification was also necessary. Likewise, Moser (1959a) stressed the importance of a suitable pH as well as sufficient nutrient levels and the presence of micronutrients for successful mycorrhizal inoculation.

Sufficient irrigation and good aeration are also essential for mycorrhizae and for successful inoculation in particular.

Several investigators have reported on the favorable effect of organic matter on mycorrhizae (e.g., Rayner, 1936, 1939; Rubtov, 1964). Addition of organic matter alone has promoted the formation of mycorrhizae. Furthermore, mycorrhizal inoculation is often associated with a liberal application of organic matter, e.g., if forest humus is used as soil inoculum, or if mycelia for pure-culture inoculation are grown on a peat or forest litter substrate.

Peat, forest humus, and compost are the most commonly used organic soil amendments in nurseries. It is, in general, hard to decide in each case which is the effective factor promoting the growth of seedlings. Thus, forest humus is often added to nursery soil to inoculate it with mycorrhizal fungi and other natural forest soil microbes, but the favorable effect on seedlings of such treatment may be due to other factors as well, such as adding macro- or micronutrients or growth substances, or to the influence of humus on the pH or physical properties (aeration or water-holding capacity) of the nursery soil. Peat and forest humus are usually more acid than the original nursery soil and therefore they may lower pH, thus making the soil more suitable for mycorrhizal fungi.

Björkman (1954, 1956), on the other hand, has shown that vigorous and richly mycorrhizal plants can be raised in a forest soil nursery with very low organic matter content if other conditions (fertilization, irrigation, aeration) are favorable.

C. Effectiveness of Different Species of Fungi

It is well known, that different species and races of *Rhizobium* vary greatly in their ability to fix atmospheric nitrogen. Corresponding differences may occur between the symbiotic efficiency of different mycorrhizal fungi. Consequently, for inoculation with either spores or pure cultures it would be most important to know which fungal species should be used with different tree species and ecological conditions.

Since the early studies of Melin (1923, 1925) numerous pure-culture experiments have revealed great differences between mycorrhizal fungi with respect to their ability to use various carbon and nitrogen compounds, growth substance requirements, and their relation to pH, temperature, and oxygen supply (e.g., Modess, 1941; Norkrans, 1950; Moser, 1958a, 1959b; Hacskaylo *et al.*, 1965; Pachlewski, 1967b; Lundeberg, 1970). These results have been supplemented by field observations (e.g., Modess, 1941). Nevertheless, very little is known about the relative effectiveness of different fungi as mycorrhizal symbionts. Of particular interest is the question of whether some species can do better than others in their ability to utilize and transmit to the host the organic nitrogen of humus compounds or difficultly soluble phosphorus and potassium minerals.

Rosendahl (1942) first showed that different species of mycorrhizal fungi may vary in capacity to dissolve phosphorus and potassium from rocks. *Boletus felleus* promoted the growth of pine seedlings more than did *B. granulatus* and *Amanita muscaria*. In this experiment, however, mycorrhizae were only formed by *Boletus felleus*. In the pot experiments of Bowen and Theodorou (1967) seedlings inoculated with *Boletus granulatus* and *Rhizopogon luteolus* utilized rock phosphate more effectively than those inoculated with *Boletus luteus* and *Cenococcum graniforme*, which, in turn, were not superior to the uninoculated controls. The growth of pine seedlings was consistently promoted more by *Boletus granulatus* and *Rhizopogon luteolus* than by *Boletus luteus* and *Cenococcum graniforme* (Theodorou and Bowen, 1970). In other experiments, in contrast, *B. luteus* was a more beneficial symbiont for pine than *B. granulatus* (Krangauz, 1967). Although none of the fungi studied by Lundeberg (1970) were able to mobilize organically bound soil nitrogen, considerable differences appeared in their ability to promote or suppress growth of the host plant (*P. sylvestris*). Great differences have also been noticed between different strains of the same species, e.g., in *Boletus scaber* (Levisohn, 1959) and *Rhizopogon luteolus* (Theodorou and Bowen, 1970). Some species may occur in nature as both mycorrhizal and nonmycorrhizal races, e.g., *Boletus subtomentosus* (Lundeberg, 1970) and *Paxillus involutus* (Laiho, 1970). Of particular interest is the unexpected observation of Lundeberg (1970) that a strain of *Boletus subtomentosus*, which was not able to form mycorrhizae on pine, was most effective in promoting the growth of pine seedlings. The favorable influence of mycorrhizal fungi on the growth of young trees even without mycorrhizal association was also demonstrated in an earlier experiment (Levisohn, 1956) (see Chapter 8).

Although it has been shown that great differences exist between different fungal species in their influence on the growth of host plants, the results have been somewhat inconsistent, and, therefore, this knowledge has so far little applicability in nursery practice. Thus, for instance, inoculation with *Paxillus involutus* greatly improved growth and survival of pine seedlings in the field (Laiho, 1970), whereas in the experiment of Lundeberg (1967), the same fungus suppressed growth. Likewise the common mycorrhizal fungus *Cenococcum graniforme*, which is very drought-tolerant and therefore has been particularly recommended for inoculation in dry areas (Trappe, 1964), has inhibited growth of seedlings in some

TABLE I

THE RELATIVE EFFECT OF DIFFERENT FUNGI ON GROWTH OF PINE SEEDLINGS[a]

Reference:	Hacskaylo and Vozzo (1971)		Theodorou and Bowen (1970)	Shemakhanova (1967)			Krangauz (1967)		Björkman (1970)	Lamb and Richards (1971)	
Tree species:	*P. caribaea*		*P. radiata*	*P. silvestris*			*P. silvestris*		*P. silvestris*	*P. radiata*	*P. elliottii*
Type of experiment:	Field	Nursery	Field	Nursery			Pot		Pot	Pot	
Measurement:	Height		Height	Dry weight			Dry weight		Dry weight	Dry weight	
Age of seedlings:	40 weeks	43 weeks	15 months	43 months	1 year			1 year	2 years	1 year	8 months
					[b]	[c]	[d]				
Boletus bovinus					166	134	117			93	
B. cothurnatus	151	120									
B. granulatus			144	133				115	90		153	608
B. luteus			122	114	105	99	99	112	244			
B. subtomentosus										144		
Cenococcum graniforme		119			231	127	118				209	581
Corticium bicolor	125	168										
Rhizopogon luteolus 1			141	129								
Rhizopogon luteolus 2			143	124								
Rh. roseolus	131	131									160	535
Scleroderma verrucosum					170	103	109					
Unidentified isol. *P. radiata*											296	231
Unidentified isol. *P. elliottii*											256	1080
Unidentified isol. *P. radiata*											324	200
Unidentified isol. *P. radiata*											497	427
Soil inoculum	141	121						139	157			

[a] 100 = uninoculated control.
[b] Sandy soil.
[c] Sandy soil, low humus content.
[d] Sandy soil, high humus content.

experiments (Lundeberg, 1970) and has been the most beneficial symbiont in others (Shemakhanova, 1967). The results of some such comparative experiments are summarized in Table I.

The varying responses of different fungi suggest that symbiotic efficiency is determined not only by the species and race of the fungus but also depends on the host species and environmental conditions (Levisohn, 1960). Thus, of the fungi tested by Krangauz (1967), *Boletus luteus* was the best symbiont for pine, whereas growth of oak was promoted most by *Hebeloma crustuliniforme*. According to Shemakhanova (1967), *Boletus luteus, B. bovinus, Scleroderma verrucosum,* and *Cenococcum graniforme* are the most suitable symbionts for pine and *Boletus subtomentosus, Amanita muscaria,* and *A. rubescens* are recommended for *Quercus*. Probably *Boletus edulis* also is a good symbiont for oak (Runov, 1967). Rayner and Neilson-Jones (1944) recommend *Boletus bovinus* as a good symbiont for pine especially in poor heath soils.

A consequence of the different temperature requirements of different mycorrhizal fungi is that some species are more adapted to cold and others to warm conditions. *Boletus plorans* is an example of a suitable species for cold habitats, whereas *Pisolithus tinctorius* probably prefers warm sites and therefore is common in the tropics (Schramm, 1966; Mikola, 1969b; Marx *et al.*, 1970).

The influence of soil fertility on the effect of different fungi is illustrated by an experiment of Mikola (1967). An unidentified ectendomycorrhizal fungus suppressed growth of *P. sylvestris* seedlings on unfertilized peat substrate when compared to uninoculated control seedlings, whereas on fertilized peat the same fungus promoted growth even more than a mixed forest humus inoculum (Table II). Furthermore, the experiments of Shemakhanova (1967) indicate that the relative efficiency of different fungi may depend greatly on the humus content of the soil (Table I).

Because of the particular requirements of individual fungal species, a

TABLE II

THE LENGTH (CM) OF THE TOP SHOOTS OF 2-YEAR-OLD PINE SEEDLINGS AS INFLUENCED BY DIFFERENT INOCULATION AND FERTILIZATION TREATMENTS[a]

	Not fertilized	Fertilized
Control, without inoculation	7.59	12.20
Inoculated with pure culture of the ectendotrophic fungus	5.51	14.05
Inoculated with a forest humus suspension	10.12	12.86

[a] From Mikola (1967).

mixed population, i.e., soil inoculum, has often been superior to any pure culture. A mixture of pure cultures of several species has sometimes been recommended for inoculation. Unidentified isolates from pine mycorrhizae have often proved much superior to pure cultures isolated from sporophores of known ectomycorrhizal fungi (Lamb and Richards, 1971; cf. Table I). Thus, there is insufficient information to give detailed instructions about fungal species which should be used for inoculation under different conditions. On the basis of experiments and practical experience, however, the following general recommendations may be suggested.

In all probability, *Rhizopogon* spp. (*R. luteolus* and *R. roseolus*) are favorable symbionts, at least for pines. Their sporophores are very common in nursery beds and young plantations in different parts of the world. Thus, soil conditions in nurseries are evidently favorable for them, which is an indispensable prerequisite for successful inoculation. They also thrive well in different forest soils (e.g., Pachlewski, 1967a; Mikola, 1969b). Crushed sporophores of *Rhizopogon* spp., mixed with soil, have been used in nursery practice for soil inoculation (Kessell and Stoate, 1938); however, the success of this treatment is unknown.

Boletus spp. belong to the best known and most intensively studied ectomycorrhizal fungi. Often numerous fruiting bodies of *B. granulatus* and *B. luteus* are seen in exotic pine plantations; therefore inoculation of nursery beds with these fungi has been suggested. However, the success of such practice is unknown. Sporophores of *Boleti* are uncommon in nursery beds, whereas those of *Rhizopogon* spp. are very common. According to Adams (1951), *Rhizopogon* spp. are the most common fungi in nurseries, whereas they are replaced by *Boleti* after transplanting into the field. *Boletus plorans* is probably the best symbiont of *Pinus cembra* for afforestation of subalpine areas, and, according to Moser (1959a), its inoculation into nursery soil is feasible. Likewise, *Boletus elegans* apparently is a very suitable symbiont for *Larix* spp. As a rule, the symbiosis between *Boletus elegans* and *Larix* spp. is easily established and no inoculation is usually necessary; infection by fungus, however, can be promoted by proper management of nursery soils.

According to Laiho (1970), *Paxillus involutus* is a suitable symbiont of trees in fertile soils and can be recommended in the afforestation of former agricultural land. So far possibilities for its inoculation on a nursery scale are unknown.

The unidentified ectendotrophic fungus, which often prevails naturally in nurseries on former agricultural soils (Mikola, 1965; Laiho, 1965; Wilcox, 1971) seems to thrive well in relatively fertile soils. If it is not present in a nursery, inoculation with it is easy.

Probably some other unidentified species also may be suitable for nursery inoculation. At least under experimental conditions, mycelia isolated from mycorrhizae have sometimes proved superior to known species (Lamb and Richards, 1971). It would be particularly important to find fungi suitable for inoculation under alkaline conditions, e.g., for *Pinus halepensis* nurseries.

III. Mycorrhizae at the Establishment of Forest Stands

A. Direct Seeding

When direct seeding is practiced in previously forested areas, mycorrhizae raise no problems. The soil always contains suitable mycorrhizal fungi and more spores come from nearby forests, and, therefore, mycorrhizae develop regularly immediately after seed germination. The fungal population usually is well adapted to local conditions, and introduction of new species has hardly any chance of success. On the other hand, there are problems if direct seeding is practiced in regions where forests of the same or related ectotrophic species are lacking.

Direct seeding is considered in Australia where shortage of labor, limited nursery capacity, and other reasons prevent the execution of extensive afforestation programs by planting only. In such cases broadcast seeding from an airplane would be a practicable solution, if the presence of mycorrhizal fungi could be secured at the same time. Mixing seed with mycorrhizal soil is possible and has proven successful in experiments, but it is impractical because of the large amount of soil needed (Forrest, 1966). Inoculation of pine seed with fungal spores has been successful on an experimental scale (Theodorou, 1971; several Soviet investigators, cf. Shemakhanova, 1967, p. 215), so that feasible methods for field use might be developed.

Mycorrhizal inoculation of tree seed has so far been practiced most widely in the Soviet Union for establishing oak shelterbelts in forest–steppe zones (cf. Lobanow, 1960; Shemakhanova, 1967). Acorns are usually sown in holes, and the mycorrhizal soil put into the same holes. The soils of the forest–steppe zone are not completely devoid of mycorrhizal fungi but inoculation greatly increases survival and early growth of the seedlings. The purpose for inoculation is both to introduce new fungi into the soil and to improve conditions for existing fungi.

To be effective, a rather large amount of soil inoculum is required. Shemakhanova (1967) recommends 2–15 gm/acorn, corresponding to 15–100 gm/seeding hole with 6–8 acorns or up to 2 m^3/hectare. Even considerably larger amounts, 250–500 gm per hole, have been used (Krasovskaya and Smirnova, 1950, cited in Shemakhanova, 1967). Suc-

cessful inoculation of acorns for field sowing with pure cultures of mycorrhizal fungi has also been reported (Runov, 1967).

As was mentioned previously, soil inoculation is not always sufficient to guarantee development of mycorrhizae and survival of the plants, and it must sometimes be supplemented with other measures, such as irrigation of phosphorus fertilization (Michowitsch, 1963). Irrigation or fertilization has sometimes had the same effect even without inoculation. Thus, several Soviet scientists consider inoculation unnecessary since the same effect can be achieved by cheaper and less laborious methods (see references in Lobanow, 1960; Shemakhanova, 1967). Whether the inoculation is beneficial or unnecessary probably depends on soil and climatic conditions. After a critical review of the literature, Lobanow (1960, p. 279) came to the conclusion that inoculation is advisable, although not necessary, in chernozem soils, but absolutely necessary in chestnut soils. Anyway, the afforestation of steppes by direct seeding requires that mycorrhizal development be encouraged by inoculation, soil amendment, or both.

B. Planting of Nursery-Grown Seedlings

1. Quality of Planting Stock

When a seedling is transplanted from the nursery into the field its environmental conditions are changed greatly, and adaptation to this radical change may be difficult. To reduce trauma, the change should be as small as possible and the seedling should be resistant to adverse conditions of the new habitat. Normally, tree seedlings in natural forest soils are mycorrhizal and, accordingly, the seedlings in the nursery should have a mycorrhizal structure that corresponds to the conditions of the planting site. Vigorous and healthy-looking nonmycorrhizal seedlings can be raised in the nursery with heavy fertilization and sufficient watering. However, the survival of such seedlings is low. Nonmycorrhizal or weakly mycorrhizal seedlings are less resistant to drought and pathogenic organisms than seedlings with well-developed mycorrhizae.

If the soil at the planting site contains a natural population of mycorrhizal fungi, even nonmycorrhizal seedlings may recover. Their adaptation to new conditions and development of mycorrhizae, however, take time which is reflected as a period of retarded growth. Björkman (1944) first suggested that the well-known stagnation of spruce seedlings after planting was due to such an adaptation and the formation of proper kinds of mycorrhizae. Later, Björkman (1953, 1954, 1956) showed that survival and early growth of seedlings after planting depended not only on their size or healthy appearance, but also on a balanced fertilization in the

nursery and mycorrhizal structure of the root systems. Accordingly, when judging the quality of planting stock, mycorrhizal relations must be considered. The abundance and structure of mycorrhizae must be included in the characteristics which are used in grading nursery stock. In general, when seedlings remain in the nursery for several years, as is customary in cool and temperate climates, they normally are mycorrhizal at the time of lifting. On the other hand, if seedlings are kept in the nursery for less than 1 year, as is a common practice for subtropical pines, or if soil sterilization and heavy fertilization are practiced, both of which retard mycorrhizal development, there is a risk that the seedlings are still nonmycorrhizal at the time of lifting, which results in poor survival after planting in the field (Jorgensen and Shoulders, 1967).

Because microscopic root examination is not possible during routine grading of nursery stock, evaluation of the mycorrhizal state must be based on visible macroscopic characteristics. In pines dichotomous branching of short roots is usually closely correlated with mycorrhizal development. The thickness and color of short roots also depend on mycorrhizal relations. Thick, light-colored, and richly branched short roots indicate healthy and vigorous mycorrhizal development. For practical purposes Göbl (1967) distinguishes between favorable and unfavorable mycorrhizal types based on branching and the color and type of the mantle. Likewise Dominik (1956) and Levisohn (1963) consider some morphological types of mycorrhizae more beneficial to the host tree than others.

2. Soil Conditions in the Planting Site

When a seedling is planted in a natural forest soil or in some other soil where mycorrhizal fungi are present, the later development of mycorrhizae depends totally on soil conditions and local fungal population. The presence and structure of mycorrhizae at the time of planting mainly influence survival and early growth of seedlings. Thus, even though nonmycorrhizal seedlings, usually, rapidly acquire mycorrhizae in the field, inoculation or other measures to promote mycorrhizal development in the nursery may be justified in order to reduce mortality or to avoid a stagnation period after planting. This is demonstrated by Theodorou and Bowen (1970). Although mycorrhizal fungi apparently were present in the soil and uninoculated seedlings rapidly developed mycorrhizae, difference in growth between inoculated and uninoculated seedlings was still detectable 32 months after planting. In the experiment of Mikola (1967), uninoculated seedlings were infected immediately after planting but the difference in growth leveled off only 3 or 4 years later.

Because ecological conditions and, consequently, fungal populations

in the nursery and in the field are often very different, local fungi gradually replace the fungal species the seedlings carried in their roots from the nursery. This change seems to take place easily and without serious disturbances to the seedlings (Mikola, 1965). A short period of growth stagnation, however, eventually may occur owing to the change of mycorrhizal population. Seedlings grown in a forest soil nursery usually have a lower mortality and shorter stagnation period than seedlings raised in former agricultural soil (Björkman, 1956, 1962). On the other hand, seedlings raised in a nursery on agricultural soil may be most suitable for afforestation of abandoned fields (Laiho, 1967).

As a whole, possibilities for selecting fungal symbionts in the nursery with respect to future planting sites are very small so far. Moser's (1962) success at afforesting alpine areas is a promising exception in this respect. More important than selecting fungal species is creating suitable physical and chemical soil conditions, both in the nursery and planting site, for mycorrhizal development (Moser, 1963; Sobotka, 1963).

IV. Other Aspects in Forestry

A. Site Evaluation

Since the number and morphology of mycorrhizae depend on ecological conditions in the soil, site quality also can be studied by observing the mycorrhizal relations. In the boreal forests, as well as elsewhere in corresponding conditions where podsol is the dominant soil type, optimum mycorrhizal development (numerous, richly branched, thick, and usually light-colored mycorrhizae) indicate healthy soil conditions, whereas slender, dark-colored short roots are signs of some deficiencies, such as shortage of nutrients or water-logged conditions (Björkman, 1942; Mikola and Laiho, 1962; Göbl, 1965).

Weak mycorrhizal development can also be an indication of a very high nutrient content of the soil (Björkman, 1942, 1949). In such cases, however, rich ground vegetation also indicates high fertility.

B. Effect of Silvicultural Practices on Mycorrhizae

If mycorrhizal studies show that defects occur in the soil, improvement can be attempted with appropriate soil amelioration. The effect of such measures may be detected in the structure of mycorrhizae even before any change in growth of trees appears. Thus, sporophores of some mycorrhizal fungi are particularly numerous in fertilized stands (Laiho, 1970). If the soil is severely deficient in a certain nutrient, such as phosphorus, the first visible effect of the addition of this nutrient is often a flush of sporophores of mycorrhizal fungi.

In water-logged soils, such as peat bogs, mycorrhizae occur only near the soil surface and even there are often dark and slender, indicating poor site conditions (Heikurainen, 1955). Artificial drainage lowers the ground water table and improves aeration, changes which are immediately reflected in the structure of mycorrhizae and their vertical distribution (Paavilainen, 1966). The production of sporophores increases at the same time. Thus, the need for both fertilization and drainage can be studied through examination of mycorrhizae. Referring to the close correlation between nutrient supply and mycorrhizal development, Björkman (1970) has suggested that perhaps forest fertilization could be replaced by some other method of activating mycorrhizal fungi.

Because mycorrhizal fungi are essential for their hosts, it is necessary to know what measures are harmful for these vital organisms. Of primary importance is the question of how mycorrhizal fungi are affected by clear cutting, i.e., the removal of the higher symbionts from the system. Romell (1930) observed that sporophores of certain fungal species never grew after clear cutting in areas where they were regularly found before the cutting; the same observation has been made by several later investigators. However, although sporophores are absent, the fungi may survive in the soil for several decades, as is shown by immediate mycorrhizal infection of seedlings if the area is reseeded. Some mycorrhizal fungi, such as *Hebeloma crustuliniforme*, *Paxillus involutus*, and *Rhizopogon* spp., are able to fruit around young seedlings, even in nursery beds, whereas some other species form sporophores only in closed stands.

Accordingly, clear cutting does not seriously harm mycorrhizal fungi unless the area remains treeless for a very long time. Even prolonged agricultural use or absence of trees for other reasons does not exterminate all ectomycorrhizal fungi. Some species possibly disappear while others survive. Controlled burning of slash, which often follows clear cutting, is a more drastic treatment; the heat may kill a part of the fungal population, and, in addition, the pH and nutrient relations in soil are altered. The heat, however, penetrates only a few centimeters and fungi which are deeper in the soil survive without injury. An experiment by Mikola *et al.* (1964) showed that intensive burning can somewhat delay the commencement of mycorrhizal infection, but not to a harmful degree.

Weed killers or other pesticides have not been found to exert a harmful influence on mycorrhizal fungi when applied at the rates which are customary in forestry practice. The harmful effect of industrial air pollutants on mycorrhizae has been observed in severely polluted areas (Sobotka, 1968).

C. Protection of Mycorrhizal Fungi

Ectomycorrhizal fungi survive persistently where they once have been established. Therefore mycorrhizal fungi, in general, do not need any particular protection. Sometimes apprehension has been expressed that collecting mushrooms, i.e., sporophores of ectomycorrhizal fungi, would be harmful to tree growth. There is no reason for such fear since collecting sporocarps has no adverse effect on the vegetative mycelia in the soil or on the mycorrhizae. On the contrary, if the sporocarps of mycorrhizal fungi, which often are extremely numerous in forest plantations, are harvested and utilized, this can considerably improve the profitability of artificial afforestation (Mikola, 1969b).

Protecting rare species of fungi as well as of other plants is a task of the conservationists. Regarding rare species of ectomycorrhizal fungi, their protection is best achieved by site protection, i.e., keeping the known habitats of such fungi forested by their probable hosts.

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